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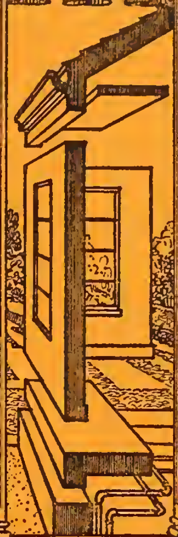

BUILDING MATERIALS AND STRUCTURES

REPORT BMS17

Sound Insulation of Wall and Floor Constructions

by

V. L. CHRISLER

NATIONAL BUREAU OF STANDARDS

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Sound Insulation of Wall and Floor Constructions

by V. L. CHRISLER

ISSUED MARCH 28, 1939

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

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Foreword

For about sixteen years the National Bureau of Standards has made measurements on the sound-insulating value of different materials and types of construction. Many of the measurements were made in cooperation with manufacturers of building materials; others were made by the Bureau to advance our knowledge of the sound-insulating properties of representative types of construction.

The funds available for the research program on building materials and structures with special reference to low-cost housing were insufficient to permit a new experimental program on sound insulation in view of more urgent needs. However, the results of the past experience of the Bureau are brought together in this report in one place so that the information may be more useful to architects and engineers.

The results show that a wall or floor which is approximately homogeneous must be excessively heavy to be a good sound insulator. If the wall or floor is built in layers which are loosely connected, the sound-insulating properties are greatly improved. Thus, method of construction is more important than nature of material. Small openings may almost completely destroy the sound-insulating value.

This report also contains a general discussion of the principles of sound insulation.

Lyman J. Briggs, *Director.*

Sound Insulation of Wall and Floor Constructions

by V. L. CHRISLER

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ABSTRACT

This report summarizes the data obtained in tests at the National Bureau of Standards on the sound transmission of wall, partition, and floor panels and gives a general discussion of the principles of sound insulation. Attention is called to the desirability of constructing buildings, in which quiet conditions are essential, in locations where the noise level is not high and of locating rooms intended to be especially quiet in parts of the building where there will be the least disturbance from the usual noises in the building. A general discussion is given of the factors which determine the transmission of sound through partitions. Impact noises and methods of insulating against them receive special mention. The importance of eliminating small openings, which may almost completely destroy the sound insulating value of a wall, is illustrated by examples. It is pointed out that the required sound insulation is less, the greater the normal noise level within the room.

I. INTRODUCTION

In the design and construction of low-cost row houses and low-rental apartments as well as better types of construction, attention should be given to preventing the transmission of sounds to insure privacy between rooms in the same apartment and between adjoining apartments. It is evident in much existing construction that more thought should have been given to the design and construction of partitions, party walls, and floors, as regards sound transmission.

In many localities outside noises have greatly increased during the past few years because of heavier traffic, especially large busses and trucks. In addition, more electric and mechanical equipment is being used which increases the amount of noise produced within the building. At the same time, for reasons of economy, there has been a tendency in modern construction to make the walls and floors as thin as practicable, which has resulted in additional transmission of sound. As a result of the inferior type of construction and increased noise level within the building, the value of the property, in many cases, is decreased. Frequently, tenants have moved to another building, hoping to be annoyed less by noises originating outside of their rooms. There is a growing demand for better sound insulation.

To aid in obtaining the necessary data for the design of structures which would have a satisfactory degree of sound insulation, in 1922 the National Bureau of Standards constructed equipment by means of which measurements could be made of the sound insulation of different types of construction. A large number of different types of partitions and floor

structures have been tested. These tests have been made on constructions ranging from heavy masonry to glass and thin fiberboards, on customary types of wall and floor structures, and on modifications of the customary types. A large portion of this work has been made possible by the cooperation of manufacturers of building materials[1].[1] This report contains the results of measurements on all constructions tested that are likely to be of interest in any type of building.

The problem of sound insulation is a very difficult one, as there are many unknown factors, and it is generally impossible to predict with any degree of certainty whether or not a partition will be a good sound insulator. As a result of the sound-transmission measurements which have been made, it is possible to make a more intelligent estimate than heretofore. There still remain, however, many elements of uncertainty. Before presenting the numerical results of the measurements of various constructions, the general principles of securing quiet buildings will be discussed.

II. LOCATION OF BUILDING

When planning a building in which it is desired to keep the noise level as low as possible, one of the first things that should be considered is location. The requirements of some buildings, such as hospitals, schoolhouses, courthouses, etc., are such that they should not be located on streets where the noise level is high unless extra precautions are taken to insulate the building against external noise. If it becomes necessary to locate such a building on a noisy street, either the windows should be eliminated and artificial illumination provided or double windows should be used and precautions taken to eliminate any leakage of sound around the windows. In either case mechanical ventilation must be specified.

Where a building is located close to railway lines, subways, elevated railways, or streets where heavy trucks are passing, it is frequently necessary to use special precautions to prevent vibrations being transmitted through the foundation into the structure. This is an important problem [2] but no attempt will be made to discuss it in this report.

[1] Figures in brackets indicate the literature references at the end of this paper.

III. LOCATION OF ROOMS WITHIN A BUILDING

Many of the more difficult problems of sound insulation can be avoided if care is taken as to the location of rooms within a building. For instance, in some Government buildings there are one or two courtrooms or hearing rooms where a low noise level is desired and a large number of other rooms used for purposes where the noise level is relatively high, for example, rooms in which typewriters and other office equipment are to be used. Frequently, a building of this type has an interior court. Under these conditions it might be possible to locate the courtroom, hearing rooms, and private offices around the interior court. In the past many buildings have been designed so that rooms facing on a court were the least desirable. From the standpoint of sound insulation, however, these rooms should be the most desirable, as it is generally possible to have the noise level in these rooms much lower than in rooms facing on the street. It must be emphasized, however, that one room located on such an interior court may destroy the quiet of all other rooms located on the court if this room is a source of noise.

Similar considerations apply to the location of rooms within dwellings, and the architect can often make a house more comfortable by suitable location of sleeping quarters, for example, with respect to the prevalent sources of noise.

A type of noise which is very disturbing and often difficult to eliminate is that from mechanical equipment. Frequently the mistake is made of locating mechanical equipment on some of the upper floors and then locating a room directly below in which a low noise level is desired. It is true that it is generally possible to place such mechanical equipment on specially designed machine bases which will eliminate most of the noise in the room below. However, if the locations of the two rooms were reversed the problem would be much simpler.

IV. FACTORS WHICH CONTROL THE TRANSMISSION OF SOUND THROUGH WALLS AND FLOORS

Noise may enter a building by the following means:

1. By transmission of air-borne sounds through openings, such as open windows or doors, cracks around doors, windows, water pipes, conduits, or the ducts of ventilating systems, etc.
2. By transmission of structural vibrations from one portion of the building to another.
3. By direct transmission through the various portions of the building structure, which act as diaphragms set in motion by the sound waves striking them.

The method of preventing the transmission of sound by the first means is quite evident, but it is not always easy to control these conditions. However, cracks can be reduced to a minimum and where a high degree of sound insulation is desired windows should be eliminated wherever possible. Ventilating ducts present a serious problem, but by inserting a properly designed acoustic filter in the duct, most of the noise can be eliminated.

Prevention of sound transmission by the second means is a structural detail which should be taken into consideration when the building is designed. Some materials do not transmit vibration as readily as others and this difference in the materials can sometimes be used to advantage. One of the most common methods is the use of a nonhomogeneous structure, or when possible, the complete separation of the two parts of the structure. This problem will be discussed further under the topic of Impact Noises.

The prevention of sound transmission by the third means is a problem which it has been possible to study in the laboratory to better advantage than when sound is transmitted by the other methods. By sound insulation of a wall, partition, or floor is meant the insulation with respect to the transmission of sound by this means. In an attempt to understand this diaphragm action, let us consider some of the factors which control the transmission of sound through a panel. Let us consider how sound passes through a sheet of window glass. The sound energy is transmitted to one side of the glass by air. The impact of the successive sound waves upon the glass causes it to be set in motion like a diaphragm, and because of this motion, energy is transmitted to the air on the opposite side. The amount of energy transmitted through the glass depends upon the amplitude of vibration of the glass. This in turn depends primarily upon four things—the initial energy striking the glass, the mass of the glass, the stiffness of the glass, and the method by which the edges of the glass are held, especially as it affects the damping of the motions of the glass. There is a fifth factor which is occasionally of importance. When the sound consists primarily of a single frequency there is a possibility that the diaphragm may be in resonance with this frequency. In this case a very large part of the sound energy is transmitted. Normally the resonance frequency of any part of a building is much lower than the frequencies of any of the ordinary sounds, and hence this condition will not generally be of importance.

V. HOMOGENEOUS WALLS

From work that has been done in the laboratory on homogeneous walls of various types, it has been determined that the weight of the wall per unit area is the most important factor in determining its sound insulation. Of secondary importance are the nature of the material and the manner in which it is fastened at the edges. There is a rather popular misconception that fiberboard and sheet lead have special properties as sound insulators. Actually, if only the sound insulating properties of the materials by themselves are considered, a sheet of steel is a slightly better sound insulator than a sheet of lead or fiberboard of the same weight per square foot, because of the greater stiffness of the steel, but the difference is not usually great enough to be of practical value. In small panels the manner of clamping the edges is of importance, but for a large panel the manner in which the edges are held makes but little difference in its value as a sound insulator.

However, attention should be called to the fact that the sound insulation factor (transmission loss in decibels) for homogeneous walls

is not directly proportional to the weight per unit area, but increases less rapidly than this factor, actually being proportional to the logarithm of the weight per unit area. This means that a high degree of sound insulation cannot be obtained in a homogeneous wall unless the wall is made exceedingly heavy.

VI. NONHOMOGENEOUS WALLS

Shortly after the study of sound insulation was undertaken it was found that the insulating value of a wall of given weight could be increased considerably if the wall were broken up into two or more layers. The surface on which the sound strikes is set in vibration as a diaphragm, but the energy from this surface has to be transferred to the next layer and then to the other side. By a proper combination of materials this energy transfer may be made quite small, and the smaller this transfer the better the wall is as a sound insulator. When a wall is thus broken up into layers, the problem becomes more complicated and it is more difficult to predict what the sound insulation factor will be.

1. Lath and Plaster Walls

A wood-stud partition, with either wood, metal, or gypsum lath, is an example of a construction for which it is difficult to predict the sound insulation. Many factors affect the sound insulation of such a structure. With walls of ordinary stud construction we have two plaster diaphragms which are on opposite sides of the partition and have common supports, where they are attached to the studs. Sound energy can then be transferred by two different paths from one side of the partition to the other. The energy of vibration of the plaster on one side can be transferred either to the studs and then across to the plaster on the other side by solid conduction, or it can be transferred to the air between the two plaster surfaces and then from the air to the second plaster surface. By experiment, it has been shown, for usual plaster construction on wood studs, that most of the energy is transferred through the studs and only a very small proportion through the air. Keeping this in mind, we may draw a few general conclusions. First, the stiffer the stud, which is the common support for the two surfaces, the smaller the amplitude of vibration, hence, the better the sound insulation. Second, if the plaster is rather weak and flabby and has considerable internal friction, a considerable portion of the energy striking it will be absorbed by internal friction and only a small portion will be transferred to the stud and from there to the other side. Hence, the stronger the plaster the poorer it will be as a sound insulator. The practical difficulty that arises here is that in the attempt to secure good sound insulation by weak plaster, the plaster may become too weak to withstand the abuse that a wall generally receives.

A rather interesting development of this idea of reducing the coupling between the wall covering and the stud has taken place in the last few years in the use of gypsum lath or gypsum plaster board. When gypsum lath was first introduced the usual method of attaching it to the studs was by nailing. This gave a rigid attachment to the studs which was undesirable from the standpoint of sound insulation. An improvement was made by attaching the gypsum lath to the stud with a resilient clip which allowed some relative movement between the lath and the stud. As these clips were a patented article, other methods of accomplishing the same result in a slightly different manner have been tried, one of which was to use a large-headed nail driven between the pieces of gypsum lath instead of through them. Another method was to use a stiff clip. Neither the large-headed nail nor the stiff clip forms a rigid fastening between the gypsum lath and stud. Hence, a wall constructed in this manner proved to be a better sound insulator than one with the gypsum lath nailed in the usual manner. The resilient clip, however, gives somewhat better results.

As in ordinary wood stud construction, most of the sound is transmitted through the stud; attempts have been made to improve such a partition by using separate studding for the two sides. This staggered-stud construction always shows some improvement over a single stud, but not as much as one might expect, for in this case considerable energy is transmitted

through the common connections at the ceiling and floor.

There is a rather general misconception that the sound insulation value of an ordinary plaster wall can be greatly increased by using some kind of filling material between the studs. While such a filler is usually advantageous as a heat insulator, the same cannot always be said of it as a sound insulator. In many cases the empty air space is acoustically the best construction. For lighter partitions a filler may be of advantage, but even here much depends upon its nature and properties. If it packs down so that it becomes rather solid, it will act as a tie between the two surfaces and frequently do more harm than good. If it is a material which is fairly elastic, so that it stays in contact with the surface layer of the partition and exerts some pressure, and if it has considerable internal friction, it may materially damp the vibration of the partition surface and thus improve the sound insulation of the partition.

Unfortunately, we have not sufficient data at present to enable us to determine without measurement exactly what kind of a material should be used as a filler and how tightly it should be packed between given surfaces so as to obtain maximum sound insulation.

2. Masonry Walls and Floors

For heavy building construction, such as load-bearing walls, a double wall will increase the sound insulation, but the fillers which have been tried seem to be of little value. However, with a masonry wall satisfactory sound insulation can be obtained in other ways which often give better results than a double wall.

In most cases it is customary to apply the plaster directly to the masonry. In this case, the wall becomes a solid unit and its weight is the most important factor. If only 3- or 4-inch tiles are used there is not sufficient weight to give satisfactory sound insulation in most cases. The problem then is one of attaching the plaster surfaces to the masonry core so as to secure as much sound insulation as possible.

To obtain some idea of the effect of keeping the plaster surface as independent of the masonry as possible, wood furring strips were tied to a 4-inch tile wall with wires which had been embedded in the mortar joints. Waterproofed paper was nailed to these furring strips, then metal lath and plaster were applied (fig. 1). The object of using paper was to prevent the plaster from pushing through the metal lath and bonding to the masonry core. It was found that this type of wall was a trifle better than an 8-inch brick wall, although it weighed approximately only one-third as much. When this was first tried out, it was believed that the method of attaching the furring strips might make considerable difference in the sound transmission. The measurements which have been taken indicate that this feature is of minor importance. There are several patented methods of attaching furring strips, but it is believed that for this type of wall construction there is little difference in the sound insulation values of these

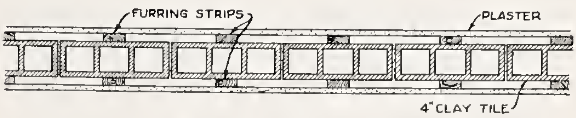


Figure 1.—*Masonry wall with furred-out plaster.*

systems as long as the plaster surface is held away from the masonry, not making direct contact at any point.

When these furred-out masonry panels were in position, conversational tests were made as well as the usual sound-transmission measurements. In every case it was found that the sound of a conversation carried on in an ordinary tone of voice was barely audible to a listener on the other side, provided he was listening intently, but that he was unable to understand anything that was said. Moreover, if there were the slightest noise in the listener's room, he failed to detect any sound of the conversation on the other side of the panel. It should be borne in mind that the rooms in which these tests were made had bare concrete walls and were so situated that no distracting noises entered from the outside. If these rooms had contained draperies and furniture to absorb part of the sound, and if there had been some noise due to traffic or other causes, the conversation would have been inaudible.

It was also found that sound insulation of a masonry floor could be greatly improved by using a floating flooring and a suspended ceiling

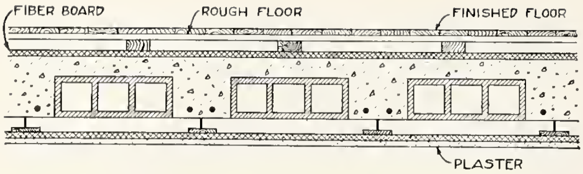


FIGURE 2.—*Floating floor and suspended ceiling*

(fig. 2). The method of attaching the nailing strips is probably of secondary importance, as in the case of furring strips attached to masonry walls. For the suspended ceiling, rigid hangers should not be used. Any flexible supports, such as springs or wires, which do not give a rigid connection should be satisfactory.

From the above discussion it is evident that the best form of sound insulation for masonry would have the following construction. What might be called the "core" of the building would be built in the customary manner, that is, with walls and floors of masonry. From this point the procedure would be different. The rooms would be formed of rough masonry and inside of these the finished surfaces would be applied. Instead of plastering on the masonry to form the wall and ceiling surfaces, these surfaces would be furred out so that the finished plaster surfaces would not be in direct contact with the masonry. Likewise, the floor would be of the "floating" type. In other words, we might picture it as a box within a box, the inner box to be attached to the outer one at as few points as possible, with these connections no more rigid than absolutely necessary.

VII. IMPACT NOISES AND METHODS OF ISOLATING THEM

Noises caused by impact, such as walking or the moving of furniture, or by a direct transfer of vibration from machines and musical instruments, such as pianos, radios, etc., form another class of noises which are more difficult to insulate than air-borne noise. These noises are also more difficult to study in the laboratory due to the limitation in size of test models. We all know from experience, that a machine often sounds as noisy in the room below as in the room where it is located. For experiments with impact noises, a special machine (fig. 3) was built. It consists of a set of five rods which are raised in succession by a set of cams. The speed of the cams is such that one rod is allowed to fall every fifth of a second. On a wood floor it is quite noisy—so much so that it is rather difficult to hold a conversation in the room. With a floor built of wood joists there is some reduction of the noise transmitted through the floor panel, but the transmitted noise is still decidedly annoying. Some contractors build a so-called "floating floor" by laying a rough flooring upon the joists, upon this a layer of fiberboard, and upon the fiberboard a finish floor which is nailed through the fiberboard to the rough floor. This form of construction was tested by the impact machine to determine whether such a structure was better, but it was found that the same percentage of sound was transmitted (within experimental error) as without the layer of fiberboard.

In another experiment a rough subflooring was laid, upon which was placed the fiberboard. On the fiberboard were laid nailing strips to which the finish floor was nailed. Such a construction is an approximation to a "floating floor." It is believed that the method of fastening these nailing strips is not of great importance. The strips can be nailed every 3 or 4 feet or held in position by various arrangements of straps. This same result can be accomplished by the use of springs or small metal chairs containing felt. For air-borne noises such structures are quite satisfactory. Under usual conditions, a conversation carried on in an ordinary tone of voice is not audible through them. For impact noises, however, such struc-

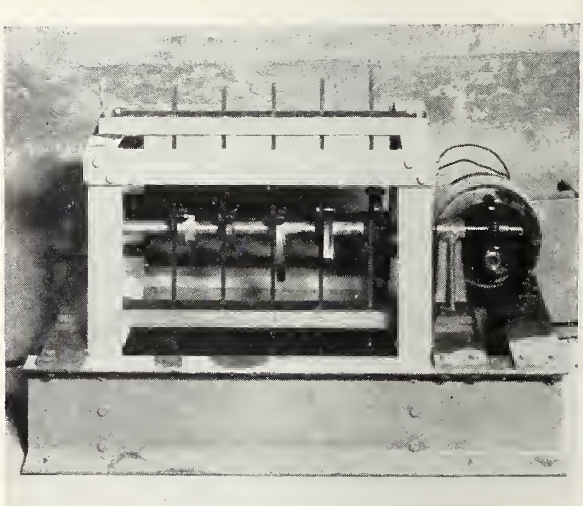


FIGURE 3.—*Machine for producing impact sounds.*

tures are rather disappointing. They are somewhat of an improvement over the usual wood structure, but footsteps can be easily heard through them.

The next attempt to improve such structures consisted of separating the ceiling and floor joists. This gave about the same result as the single set of joists and floating floor, although not quite as satisfactory. A floating floor was then added. This combination gave the best results that were obtained with wood joists and was very satisfactory as far as air-borne noises were concerned. The insulation value for impact noises, however, was not as great as could be desired.

Another type of floor which was studied was masonry. When impacts were applied directly to the masonry floor, the noise in the room below was practically as loud as in the room where the machine was located. A floating floor was then built, resulting in decided improvement. Finally, a suspended ceiling was added and this gave the best result which had been obtained (fig. 2). For one of the listening tests a radio loudspeaker was used. The loudspeaker was operated at a somewhat higher volume than is customary for home use, and when listening through the panel the sounds were very faint. It is certain that if the test had been made anywhere except in a room which was absolutely quiet, the radio could not have been heard at all.

For impact noises this construction was not as good as for air-borne noises, but it was a decided improvement over masonry slab. The noise from the impact machine was distinctly audible, but not loud enough to be very noticeable if two people were talking in the room. The results in this case were more satisfactory than for wood joists.

In the foregoing discussion the difference between the noise levels in the rooms above and below the floor panel only has been considered. By changing the floor covering, the noise level in both rooms may be greatly reduced, although the insulation factor may not be changed enough to be of any practical value.

For noises which originate from impacts on the floor, the floor covering acts somewhat in the nature of a shock absorber. Hence, the softer and more yielding the floor covering, the less the amount of energy transferred to the floor to be radiated as noise. For instance, the noise produced by walking on a floor covered with rubber or cork tiles is somewhat less than that produced when walking on bare concrete; while that produced when walking on a heavy carpet is very much less than that produced by walking on a concrete floor.

The amount of noise generated also depends upon the type of object which strikes the floor. As two extremes, let us consider the leather heel of a shoe with an iron clip on the bottom versus a rubber heel. The impact of these two kinds of heels on a concrete floor will produce a noise level having a difference of several decibels. If the floor covering consists of rubber or cork tiles, the difference in the noise levels produced by these two types of heels is smaller. If we use a still softer material for a floor covering, such as a heavy carpet, the difference in the noise levels produced by the two types of heels becomes negligible. Considerable sound energy may be transmitted through the legs of a piano or radio into the floor. This can be partly eliminated by putting the legs of the piano or radio in caster cups and then putting rubber between the caster cups and the floor. Vibrations from machinery which are carried into a building structure and cause noise throughout the building may be largely eliminated in a somewhat similar manner. In this case a resilient mounting, having a considerable amount of internal damping, is placed between the machine and the building structure.

VIII. EFFECT OF OPENINGS AND METHODS OF COMPUTING RESULTS

In the foregoing discussion, the fact that all rooms have either doors or windows or both has been ignored. A window or a door in a partition will frequently transmit more sound than the rest of the partition, although sealed around the edges so that it is airtight; hence, it may be useless to do anything to the partition to improve its sound insulation as long as the door or window remains in the partition.

To bring out this point, it will be necessary to discuss rather briefly how to compute the total sound transmitted through a wall composed of several elements having different coefficients of

transmission and the manner in which these results are usually expressed.

First, let us consider the usual manner of expressing values of sound insulation and why they are expressed in that way. In most cases, we are interested in the effect of sound upon the human ear, therefore, an attempt has been made to express the results so that they are approximately proportional to what the ear hears. It has been found that the ear does not respond in proportion to the energy of the sound. As the energy of a sound increases steadily, the response of the ear fails to keep pace with it. There appears to be in the ear a regulating or protective mechanism which, like the well-known mechanism of the eye, protects the organ against excessive stimulation. Experiment shows that the response of the ear is approximately proportional to the logarithm of the sound energy; that is, energies proportional to 10, 100, and 1,000 would produce in the ear effects proportional to 1, 2, and 3, respectively.

A slight modification of this logarithmic scale has come into general use to measure sound energy and the amount of noise reduction. It is called the decibel scale. This scale merely multiplies the numbers of the logarithmic scale by 10. The unit of this scale, the decibel, is a rather convenient unit as it is approximately the smallest change in energy that the average ear can detect. For this reason this unit has frequently been called a sensation unit.

The decibel scale is suitable for measuring ratios of sound intensity. To measure absolute noise levels the zero value is assigned to a definite level, i. e., a level of 20 decibels corresponds to an energy 100 times that corresponding to the zero value.

To understand a little more clearly what is meant by different sound energies in decibels, and how much this energy may be reduced by a structure, figure 4 should be referred to. This has been made up from the results of various noise measurements and gives an approximate idea of the value of different noise levels in decibels.

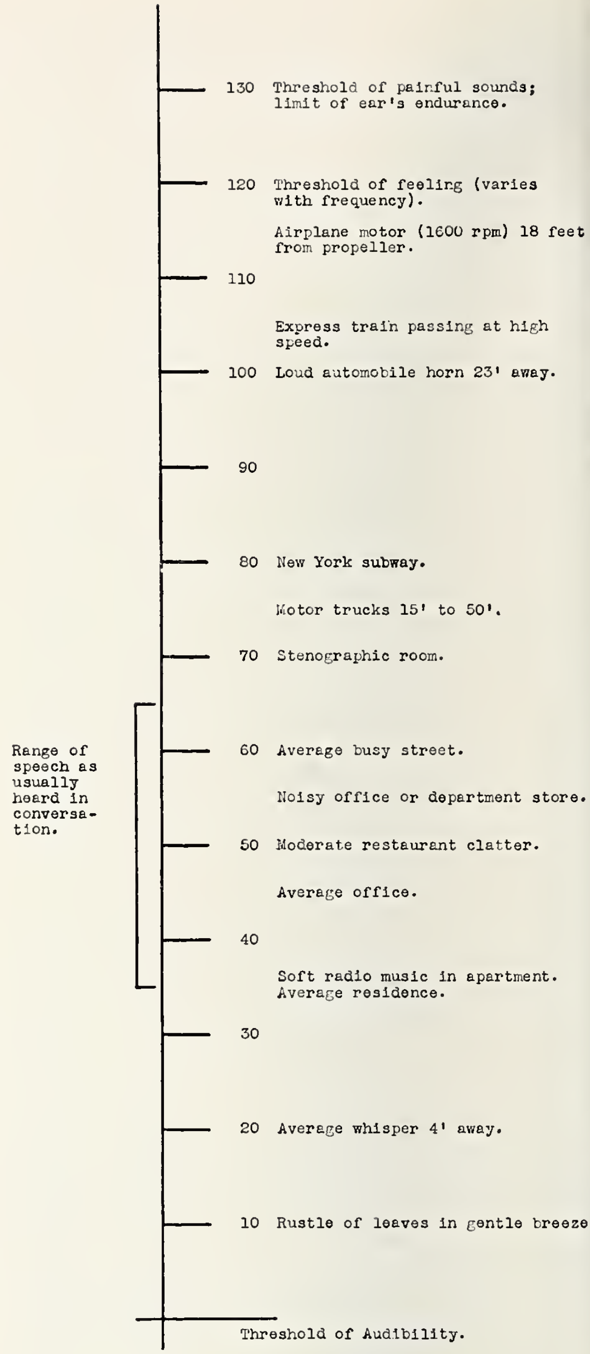


FIGURE 4.—*Decibel scale of sound intensities.*

The noise-reduction factor as referred to in this report is the difference in sound energy expressed in decibels, as a result of the presence of the wall or panel between the sound and hearer.

It can be shown [3] that if E_1 is the energy level of the noise outside of a room, and E_2 the energy level in the room

$$\frac{E_1}{E_2}=\frac{A}{\tau_1 s_1+\tau_2 s_2+\tau_3 s_3}, \qquad (1)$$

where A is the total absorption in the room, s_1, s_2, s_3, etc. are the areas of the various portions of the walls, such as walls, windows, etc., and τ_1, τ_2, τ_3, are their respective coefficients of sound transmission or acoustic transmittivity, that is, the fraction of the incident sound energy that is transmitted through the panel. The value of τ is seldom published. Instead, the value of 10 $\log_{10} 1/\tau$, which is called the transmission loss in decibels, is given. The denominator $(\tau_1 s_1+\tau_2 s_2+ \ . \ . \ .)$ is termed the total transmittance, and will be represented by T. Equation 1 can be rewritten

$$E_1/E_2=A/T. \qquad (2)$$

The noise-reduction factor in decibels, which is the difference between the noise level outside of a room and the noise level in the room, is equal to

$$10\ (\log_{10}E_1-\log_{10}E_2)=10\ \log_{10}E_1/E_2 =10\ \log_{10}A/T \qquad (3)$$

and the quantity 10 $\log_{10}A/T$ is called the noise reduction factor.

To illustrate the use of these formulas and show the detrimental effect of doors and windows, let us assume the case of a brick building containing a single room. The walls are of 8-inch brick and the roof a 6-inch reinforced-concrete slab. The total absorption in the room which has been acoustically treated is assumed to be 400 units. It is assumed also that the foundations and floor are built in such a manner that the amount of sound which enters the room through the floor is negligible. Assuming usual values for the transmission losses through the various parts, we may tabulate the separate items as follows:

Material	Areas, s	Transmission loss	τ	τs
	ft^2	*Decibels*		
8-inch brick walls, plus plaster	1,200	54	0.0000040	0.0048
6-inch cement roof slab, plus plaster	600	50	.000010	.0060
Windows	150	28	.0016	.24
Door	21	35	.00032	.0067
Total transmittance, T, equals				0.2575

Noise-reduction factor (in decibels) = 10 $\log_{10}(A/T)$ = 10 $\log_{10}(400/0.258)$ = 31.9 decibels.

From the last column in the above table it may be noted that the windows admit many times the amount of sound admitted by all of the wall and ceiling structures, and that the door admits more noise than either the walls or ceiling.

If one window is open so that there is 1 square foot of open window, the transmission loss through an opening like this is zero, hence $\tau=1$ and $\tau s=1$. In other words, an opening of 1 square foot would transmit four times the sound energy that is transmitted by the entire structure with closed windows. The noise reduction factor with the partly opened windows is diminished to 25.0 decibels.

Frequently, the question arises as to how such a computation would be made in the case of an apartment room where one side is exposed to street noise, with adjoining rooms on two sides, and the fourth side adjacent to a corridor.

Let us assume the case of a rectangular room, the width of which facing on the street is 10 feet, the length 12 feet, and the height 9 feet. Also, let us assume that the outer wall is a 13-inch brick wall having one window 3 feet by 5 feet, and that the interior walls are 4-inch clay tile plastered on both sides, having one door 3 feet by 7 feet, entering from the corridor. Assume the street noise to be 80 decibels, the peak noises caused by loud talking and laughter in the room on one side to be 75 decibels, the peak noise in the other room to be 60 decibels, and in the corridor, 60 decibels. We shall neglect all sound coming through the floor or ceiling. The total absorption by carpet, draperies, furniture, etc., will be considered as 70 units. The absorption is computed as outlined in reference [4].

If the noise-reduction factor for each wall is computed as before, the following is obtained:

EXTERIOR WALL

Material	Areas, s	Transmission loss	τ	τs
	ft^2	*Decibels*		
13-inch brick wall, plus plaster on one side	75	57	0.0000020	0.00015
Window	15	28	.0016	.0240
Total transmittance, T, equals				0.0242

Noise-reduction factor (in decibels) = 10 $\log_{10}(A/T)$ = 10 $\log_{10}(70/0.0242)$ = 34.6 decibels.

WALL BETWEEN ROOMS

Material	Areas, s	Transmission loss	τ	τs
	ft^2	*Decibels*		
4-inch clay tile wall, plus plaster on both sides	108	44.0	0.000040	0.00432
Total transmittance, T, equals				0.0043

Noise-reduction factor (in decibels) $=10 \log_{10} (70/0.0043)=42.1$ decibels.

WALL BETWEEN ROOM AND CORRIDOR

Material	Areas, s	Transmission loss	τ	τs
	ft^2	*Decibels*		
4-inch clay tile wall plus plaster on both sides	69	44.0	0.000040	0.0028
Door	21	35.0	.00032	.0067
Total transmittance, T, equals				0.0095

Noise-reduction factor (in decibels) $=10 \log_{10} (70/0.0095)=38.7$ decibels.

The noise in the room caused by street noise only would be $80.0-34.6=45.4$ decibels. That from the noisiest room would be $75-42.1=32.9$ decibels. That from the quietest room, $60-42.1=17.9$ decibels, and that from the corridor, $60-38.7=21.3$ decibels.

The approximate peak noise level can be obtained as follows:

$$\begin{aligned}
\text{Anti}\log_{10}(45.4/10) &= 34700\\
\text{Anti}\log_{10}(32.9/10) &= 1950\\
\text{Anti}\log_{10}(17.9/10) &= 60\\
\text{Anti}\log_{10}(21.3/10) &= 140\\
\hline
&\quad 36850
\end{aligned}$$

$$10 \log_{10} 36850=45.7 \text{ decibels.}$$

In other words, the street noise, because of the poor insulation of the window, is the predominating noise, but it may not be the most annoying one, as the intermittent noise resulting from loud talking and laughing may be more disturbing than a steady noise. Furthermore, with a level of 32.9 decibels it should be possible to understand a large portion of any conversation carried on in the adjoining room.

The values given for transmission losses are approximate for doors and windows, and are used merely to illustrate the fact that with a door or window in a wall it may be impractical to attempt to make the rest of the wall a good sound insulator, inasmuch as a small opening, such as a crack under a door, will greatly reduce the sound insulation. The same is true of ducts or any other opening which may connect two rooms.

In equation 3 the total absorption comes in the numerator, hence the noise level can be reduced by increasing the total absorption in the room. Generally, however, this reduction is not large, being of the order of about 5 decibels as between a treated and an untreated room. This means that the introduction of absorbent material to reduce the noise level caused by noises originating outside of the room is of little value, since a much greater reduction can generally be obtained at less cost by increasing the sound insulation of the boundaries of the room. This does not mean that sound absorbent materials [4] are of no value, for they are necessary to keep down the noise level resulting from noises originating in the room. Absorbent material prevents corridors from acting as speaking tubes and transmitting sound from one room to another when the doors are open. Other illustrations could be given of the value of sound absorption, but the fact should be emphasized that sound absorption cannot take the place of sound insulation.

IX. MASKING EFFECT

There remains one other important question, namely, what should be the transmission loss of a partition to give satisfactory results?

It has often been stated that a certain type of partition built in one place has been very satisfactory, yet the same type of partition used in another place is not satisfactory. It is believed that in these cases the conditions of local noise are entirely different, hence the apparent failure in one case. Whether a partition is satisfactory or not depends on what is heard through it. What one hears through a partition depends upon the amount of general noise in the locality as well as upon the noise level in the adjacent room, and the transmission loss of the partition.

For example, in the country or in a place where the general noise level is very low it might be possible to hear almost everything that occurs in an adjoining room, but if this same building were in a downtown district where the noise level is high, comparatively little would be heard from the adjoining room.

In other words, there is a masking effect because of the presence of other noises and this should be taken into consideration. This masking effect of noise is much the same as if the listener were partially deaf, since his threshold of hearing is shifted slightly upwards.

In what is ordinarily considered a quiet room this masking effect may raise the threshold of hearing as much as 5 or 10 decibels, and in an ordinary business office as much as 10 to 20 decibels. In a noisy shop or factory this masking effect is considerably greater.

Unfortunately, there have been very few measurements made to determine the masking effect of complex noises; hence, there is not enough information available to determine what the masking effect of a given noise level will be.

X. MAXIMUM NOISE LEVELS WHICH SHOULD BE TOLERATED

A more practical way to determine the type of partition that should be used to secure definite results is to determine the noise level one is willing to tolerate in a room. From a knowledge of this and the noise level existing on the other side of the partition, the transmission loss through the partition required to reduce the noise to the desired level can be computed from the formulas given in section VIII.

The loudness of various noises has been measured by different listeners, and the results published [3, 6]. There is very little information regarding which noise levels should be tolerated, but Knudsen [3] makes the following recommendations:

Location	Maximum noise level which should be tolerated
	Decibels
Studios for the recording of sound (talking-picture studios)	6 to 8
Radio broadcasting studios	8 to 10
Hospitals	8 to 12
Music studios	10 to 15
Apartments, hotels, and homes	10 to 20
Theaters, churches, auditoriums, classrooms, and libraries	12 to 24
Talking-picture theaters	15 to 25
Private offices	20 to 30
Public offices, banking rooms, etc	25 to 40

Attention should be called to the fact that the above levels are those desired but seldom found in practice. Special attention is directed to the low noise level recommended for hospitals. This low level is desirable; but, because of the usual construction and location of hospitals, the level is generally very much higher. The transmission loss of numerous types of construction from which the reduction factors can be computed may be found in Architectural Acoustics [3], Acoustics and Architecture [5], and in the publications of the National Bureau of Standards [1]. Many of the results obtained at the National Bureau of Standards are given in this report.

With this information it should be possible to design a floor or partition which will give satisfactory sound insulation for most conditions.

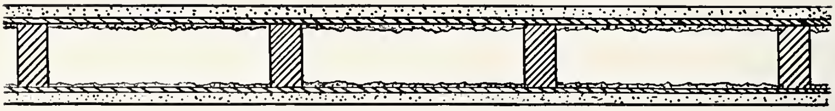
XI. PANEL CONSTRUCTION AND TRANSMISSION LOSS, IN DECIBELS

Tables 1 and 2 give a summary of the results of sound-transmission measurements made at the National Bureau of Standards which, with a few exceptions, have been published in previous papers. In the earlier papers the term "reduction factor" was used and the measurements made in a somewhat different manner than in Research Paper RP800. In this paper the results are given in the form of transmission loss in decibels.

The frequency bands at which measurements have been taken have been varied from time to time. The frequencies given in the following table are approximately the middles of these bands.

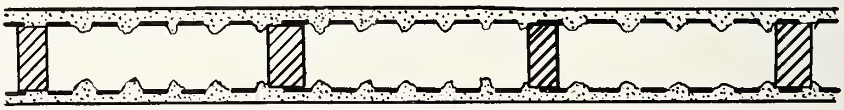
The panel numbers are those given in the original publications.

The results for panels 25 and 26 were originally published in Scientific Paper of the National Bureau of Standards S552, for panels 60 to 128 in Research Paper RP48, and for panels 129 to 147, except 137A and 137B, in Research Paper RP800. The results for panels 137A, 137B, and 148 to 169 have not been previously published. In the table, two columns of averages are given. The first column gives the average transmission loss for frequencies 256 to 1,024 cycles. In the second column an average is given only when measurements have been made at nine frequencies. This column then represents the average transmission loss between 128 and 4,096 cycles per second.



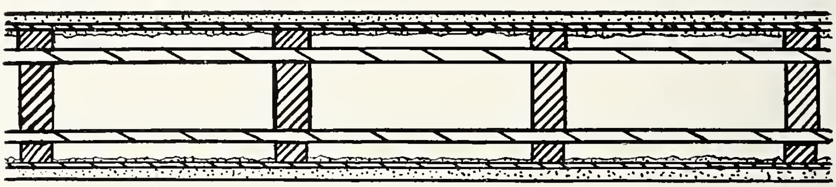
PANELS 162, 163, 119

PANEL 162.—*Wood studs; wood lath; scratch and brown coats of lime plaster; smooth, white finish.*
PANEL 163.—*Wood studs; wood lath; scratch and brown coats of gypsum plaster; smooth, white finish.*
PANEL 119.—*Same construction as panel 163.*



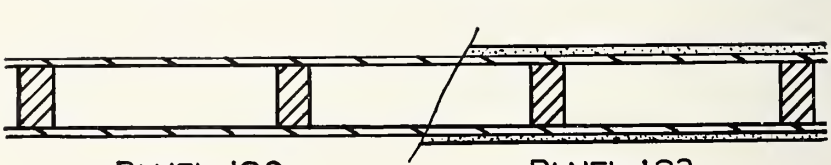
PANELS 164 & 165

PANEL 164.—*Wood studs; metal lath; scratch and brown coats of lime plaster; smooth, white finish.*
PANEL 165.—*Wood studs; metal lath; scratch and brown coats of gypsum plaster; smooth, white finish.*



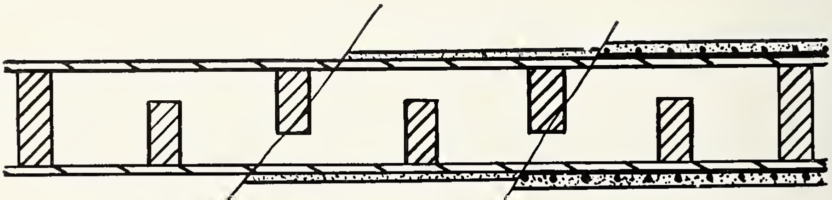
PANEL 86

PANEL 86.—*Wood studs; ½-inch Flaxlinum nailed to each side of 1- by 2-inch furring strips; wood lath, plastered on both sides with scratch and brown coats of gypsum plaster; smooth, white finish.*



PANEL 120 PANEL 123

PANEL 120.—*Wood studs; ½-inch Insulite applied to both sides; joints filled.*
PANEL 123.—*Wood studs; ½-inch Insulite; scratch and brown coats of gypsum plaster; smooth, white finish.*



PANEL 124 PANEL 126 PANEL 125

PANEL 124.—*Staggered wood studs; ½-inch Insulite applied to both sides; joints filled.*
PANEL 126.—*Staggered wood studs; ½-inch Insulite; scratch and brown coats of gypsum plaster; smooth, white finish.*
PANEL 125.—*Staggered wood studs; ½-inch Insulite; Ecod fabric; scratch and brown coats of gypsum plaster; smooth, white finish.*

TABLE 1.—*Sound-transmission loss—wall structures*

Panel	Transmission loss (in decibels) at frequencies (cycles per second)													Weight
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	
WOOD STUDS														
														lb/ft^2
162	27.4	------	27.3	36.3	38.1	41.0	43.5	50.2	54.9	------	59.9	41.8	42.1	15.6
163	31.6	------	29.0	18.4	34.4	33.2	39.9	36.8	40.1	------	58.2	32.5	35.7	15.1
119	------	38.2	------	39.6	------	39.2	------	43.9	49.0	58.8	------	40.9	------	17.4
164	26.4	------	34.2	40.6	39.7	43.7	48.7	52.3	56.1	------	58.1	45.0	44.4	19.8
165	31.0	------	26.0	34.5	31.5	38.2	43.6	42.6	44.7	------	61.1	38.1	39.2	20.0
86	------	------	------	42.4	------	38.2	------	44.7	54.1	61.7	------	41.8	------	14.7
120	------	28.5	------	28.6	------	24.0	------	35.6	47.5	50.7	------	29.4	------	5.1
123	------	46.2	------	39.5	------	47.2	------	57.0	56.3	55.2	------	47.9	------	13.3
124	------	34.1	------	29.9	------	27.9	------	41.8	59.3	60.1	------	33.2	------	4.94
126	------	50.1	------	52.2	------	49.4	------	59.6	60.1	53.8	------	53.7	------	13.1
125	------	52.2	------	52.6	------	47.4	------	53.7	58.2	62.7	------	51.2	------	16.1

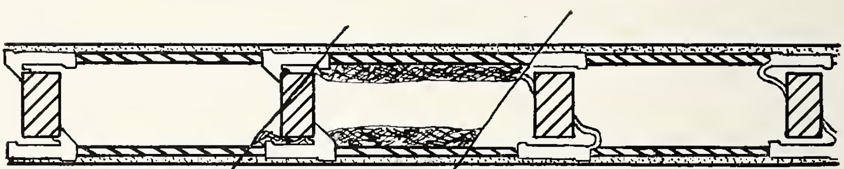
PANEL 127

PANEL 127.—*Wood studs; ½-inch Insulite applied to one side, plastered and back plastered; metal lath applied to opposite side and plastered with scratch, brown, and finish coats.*

PANELS 148 & 149

PANEL 148.—*Wood studs; gypsum lath nailed to studs with nails approximately 6 inches apart; scratch and brown coats of sanded gypsum plaster; smooth, white finish; thickness of plaster ½-inch.*

PANEL 149.—*Wood studs; gypsum lath held on with special nails with large heads, the nails being driven between the sheets of gypsum lath; scratch and brown coats of sanded gypsum plaster; smooth, white finish; thickness of plaster ½ inch.*



PANEL 153 PANELS 151,152 PANEL 150,167

PANEL 153.—*Wood studs; gypsum lath attached to studs with stiff clips; scratch and brown coats of gypsum plaster; smooth, white finish; thickness of plaster ⅜ inch*

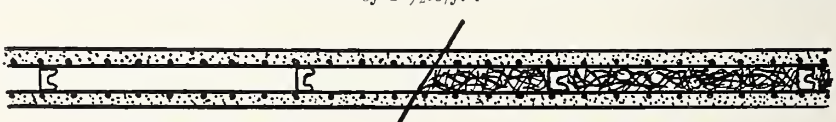
PANEL 151.—*Same as panel 153, except that ½-inch felt was glued to back of gypsum lath.*

PANEL 152.—*Same as panel 151, except that plaster was ½ inch thick instead of ⅜ inch.*

PANEL 150.—*Wood studs; gypsum ath attached to studs by spring clips; scratch and brown coats of gypsum plaster; smooth, white finish; thickness of plaster ½ inch.*

PANEL 167.—*Same as panel 150, except spring clips were made by different firm.*

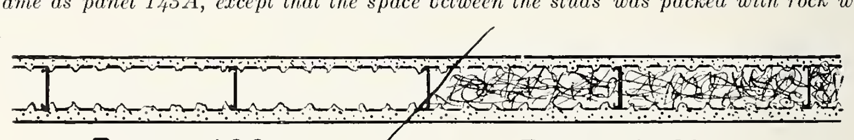
PANEL 168.—*Same as panel 167, except that the space between the studs was filled with glass wool and packed to a density of 1 ½lb/ft^3.*



PANEL 143A PANEL 143B

PANEL 143A.—*Constructed of 1½-inch Steeltex channels for studs; Steeltex lath; scratch and brown coats of gypsum plaster; smooth, white finish.*

PANEL 143B.—*Same as panel 143A, except that the space between the studs was packed with rock wool.*



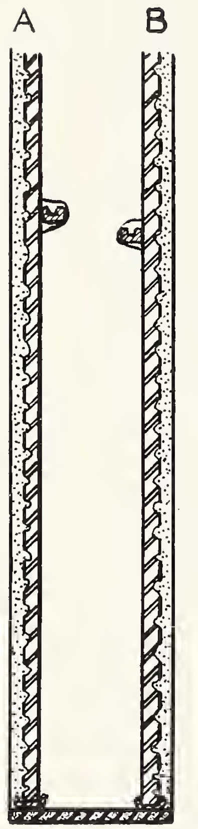
PANEL 166A PANEL 166B

PANEL 166A.—*Constructed of 3-inch one-piece metal studs spaced 16 inches on center; expanded metal lath; scratch and brown coats of gypsum plaster; smooth, white finish.*

PANEL 166B.—*Same as panel 166A, except that the space between the studs was filled with rock-wool bots and packed to a density of 4.3 lb/ft^3.*

TABLE 1.—*Sound-transmission loss—wall structures*—Continued

Panel	Transmission loss (in decibels) at frequencies (cycles per second)													Weight
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	
WOOD STUDS—Continued														
														lb/ft²
127	------	45. 4	------	45. 1	------	44. 7	------	47. 6	57. 7	59. 0	------	45. 8	------	20. 9
148	32. 6	------	27. 8	31. 0	34. 9	39. 2	44. 3	45. 6	48. 7	------	65. 9	39. 0	41. 1	15. 2
149	32. 5	------	41. 0	38. 9	43. 2	45. 7	50. 6	50. 4	55. 1	------	71. 6	45. 8	47. 7	15. 7
153	30. 9	------	37. 2	40. 5	41. 7	46. 2	51. 3	51. 2	53. 8	------	67. 2	46. 2	46. 7	------
151	29. 6	------	37. 6	39. 9	44. 9	47. 1	56. 6	60. 8	60. 3	------	70. 2	49. 9	49. 7	------
152	37. 4	------	40. 4	42. 4	45. 3	46. 5	55. 4	60. 6	61. 8	------	68. 2	50. 0	50. 9	17. 2
150	51. 0	------	42. 3	48. 1	48. 4	50. 0	56. 3	56. 4	47. 6	------	65. 8	51. 8	51. 8	------
167	45. 1	------	52. 9	45. 0	48. 1	47. 4	53. 0	55. 4	53. 1	------	66. 7	49. 8	51. 9	15. 7
168	47. 5	------	50. 1	49. 1	53. 2	53. 2	55. 9	58. 0	57. 6	------	68. 2	53. 9	54. 8	16. 9
STEEL STUDS														
143A	17. 7	------	------	20. 6	------	27. 2	------	42. 7	39. 2	------	57. 8	30. 2	------	17. 6
143B	25. 7	------	------	24. 0	------	36. 8	------	46. 7	49. 8	------	69. 1	35. 8	------	------
166A	29. 9	------	27. 4	28. 4	35. 3	34. 8	40. 1	40. 0	42. 6	------	53. 4	35. 7	36. 9	19. 6
166B	34. 3	------	34. 9	30. 9	33. 5	40. 1	38. 0	39. 4	39. 6	------	51. 7	36. 4	38. 0	21. 1



PANELS 159, 160A - 160I

Panel 159.—*Panel A only—Metal studs of ¾-inch channel iron expanded metal lath; scratch and brown coats of gypsum plaster; smooth, white finish, applied to only one side.*

Panel 160A.—*Two panels similar to panel 159 placed back to back and resting on cork 1-inch thick; distance from face to face of panels 10 inches.*

Panel 160B.—*Same as panel 160A, except distance from face to face 8½ inches.*

Panel 160C.—*Same as panel 160A, except distance from face to face 7 inches.*

Panel 160D.—*Same as panel 160A, except distance from face to face 5½ inches.*

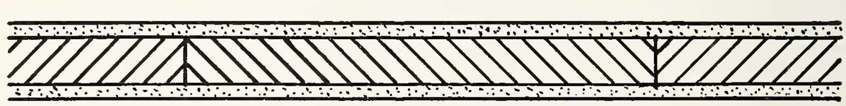
Panel 160E.—*Same as panel 160A, except distance from face to face 4½ inches.*

Panel 160F.—*Same as panel 160A, except distance from face to face 4⅜ inches, and braces at corners are in contact with each other.*

Panel 160G.—*Same as panel 160E, except cork was removed and a 1-inch board was placed under the panels to carry the load.*

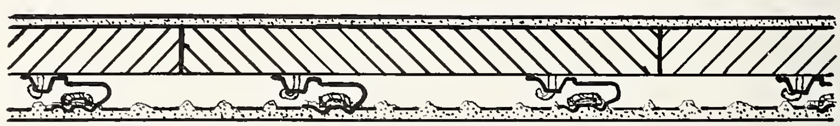
Panel 160H.—*Same as panel 160G, except board was removed and concrete substituted for the board.*

Panel 160I.—*Same as panel 160H, except the two panels were tied together at two points with a shoe made of ¾-inch channel iron, each point being approximately 18 inches in the horizontal direction from the center of the panel.*



PANEL 161

Panel 161.—*3- by 12- by 30-inch gypsum tile; brown coat of gypsum plaster; smooth, white finish.*

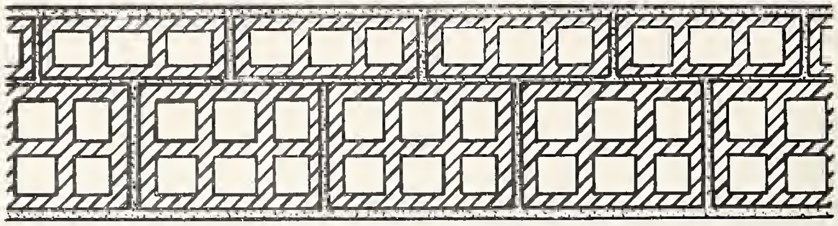


PANEL 138

Panel 138.—*3- by 12- by 30-inch gypsum tile; United States Gypsum resilient clip; metal lath and gypsum plaster on one side; gypsum plaster applied directly to tile on the other side; smooth, white finish on both sides.*

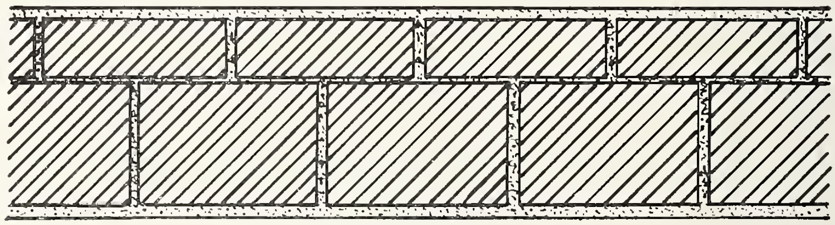
TABLE 1.—*Sound-transmission loss—wall structures*—Continued

Panel	Transmission loss (in decibels) at frequencies (cycles per second)													Weight
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	
STEEL STUDS—Continued														
														lb/ft^2
159	26. 8	------	30. 8	28. 8	33. 3	34. 7	36. 1	32. 8	32. 2	------	43. 8	33. 1	33. 3	8. 1
160A	50. 0	------	49. 9	47. 8	52. 4	53. 4	56. 8	54. 6	60. 0	------	71. 8	53. 0	55. 2	17. 2
160B	48. 7	------	51. 0	46. 1	51. 8	53. 2	56. 7	54. 4	58. 4	------	71. 8	52. 4	54. 7	17. 2
160C	51. 0	------	49. 0	44. 4	51. 1	52. 9	55. 7	54. 5	55. 6	------	72. 5	51. 7	54. 1	17. 2
160D	43. 4	------	49. 3	45. 3	49. 6	51. 6	55. 8	51. 0	61. 1	------	72. 7	50. 7	53. 3	17. 2
160E	43. 1	------	50. 5	43. 1	48. 3	50. 6	54. 8	50. 2	61. 6	------	73. 6	49. 4	52. 9	17. 2
160F	44. 1	------	48. 7	42. 9	45. 6	47. 0	52. 0	49. 4	57. 1	------	71. 9	47. 4	51. 0	17. 2
160G	44. 5	------	52. 7	44. 0	46. 2	45. 6	53. 7	49. 7	55. 9	------	69. 5	47. 8	51. 3	17. 2
160H	46. 4	------	45. 5	44. 0	43. 2	47. 8	51. 0	46. 2	49. 2	------	59. 6	46. 4	48. 1	17. 2
160I	43. 0	------	39. 9	41. 4	42. 7	46. 3	48. 3	45. 7	45. 9	------	58. 2	44. 9	45. 7	17. 2
GYPSUM TILE														
161	28. 9	------	30. 9	35. 7	38. 5	36. 2	37. 0	41. 5	46. 8	------	47. 2	37. 8	38. 1	21. 0
138	45. 4	------	------	44. 4	------	54. 7	------	59. 1	61. 9	------	80. 0	52. 7	------	----



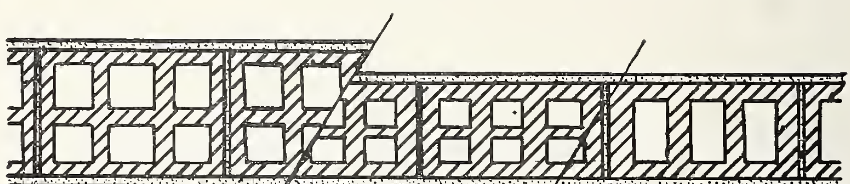
PANEL 60

Panel 60.—*Hollow clay tile panel (two units, $3\frac{3}{4}$ by 12 by 12 inches and 8 by 12 by 12 inches); end construction; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*



PANEL 61

Panel 61.—*Hollow clay tile panel (two units, $3\frac{3}{4}$ by 5 by 12 inches and 8 by 5 by 12 inches); side construction; plastered both sides with brown coat of gypsum plaster; smooth white finish.*



PANEL 62 PANEL 63 PANELS 64 & 65

Panel 62.—*Hollow clay tile panel constructed of 8- by 12- by 12-inch tile, six cells; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*

Panel 63.—*Hollow clay tile panel constructed of 6- by 12- by 12-inch load-bearing partition tile, six cells; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*

Panel 64.—*Hollow clay tile panel constructed of 6- by 12- by 12-inch partition tile, medium burned, three cells; plastered both sides with brown coat of gypsum plaster; smooth, white finish.*

Panel 65.—*Hollow clay tile panel constructed of 6- by 12- by 12-inch soft partition tile, three cells; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*

PANELS 66, 140, 141, 142 PANELS 68 & 69

Panel 66.—*Hollow clay tile panel constructed of 4- by 12- by 12-inch partition tile, three cells; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*

Panel 140.—*Hollow clay tile panel constructed of standard 4- by 12- by 12-inch New Jersey porous clay tile; plastered on both sides with $\frac{5}{8}$ inch of brown coat gypsum plaster; smooth, white finish.*

Panel 141.—*Hollow clay tile panel constructed of 4- by 12- by 12-inch New Jersey hollow clay tile with 1-inch shells; plastered on both sides with $\frac{5}{8}$ inch of brown coat gypsum plaster; smooth, white finish coat.*

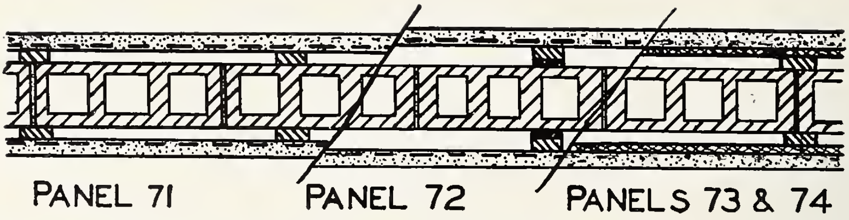
Panel 142.—*Hollow clay tile panel constructed of 4- by 12- by 12-inch New Jersey standard clay partition tile; plastered on both sides with $\frac{5}{8}$ inch of brown coat gypsum plaster; smooth, white finish coat.*

Panel 68.—*Hollow clay tile panel constructed of 3- by 12- by 12-inch partition tile, three cells; plastered both sides with brown coat of gypsum plaster; smooth, white finish.*

Panel 69.—*Built as nearly like panel 68 as possible.*

TABLE 1.—*Sound-transmission loss—wall structures*—Continued

Panel	Transmission loss (in decibels) at frequencies (cycles per second)													Weight
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	
CLAY TILE														
														*lb/ft*²
60				49. 4		40. 1		37. 0	55. 2	53. 6		42. 2		65. 0
61				49. 4		46. 3		48. 7	53. 3	52. 2		48. 1		66. 0
62				44. 3		44. 5		48. 9	58. 0	53. 2		45. 9		48. 0
63				38. 8		42. 1		46. 6	53. 5	54. 7		42. 5		39. 0
64				41. 2		37. 4		45. 1	52. 1	52. 7		41. 2		37. 0
65				41. 1		42. 0		43. 7	50. 1	45. 9		42. 3		37. 0
66				41. 1		40. 0		41. 5	49. 9	47. 3		40. 9		29. 0
140	31. 2			31. 0		35. 9		46. 6	50. 2		57. 7	37. 8		27. 5
141	30. 0			35. 4		43. 5		51. 5	55. 7		65. 1	43. 5		37. 5
142	33. 3			32. 8		42. 1		46. 2	49. 4		61. 8	40. 4		33. 4
68				40. 7		35. 9		43. 3	51. 0	51. 2		40. 0		28. 0
69				41. 7		41. 4		43. 7	49. 8	50. 3		42. 3		28. 0

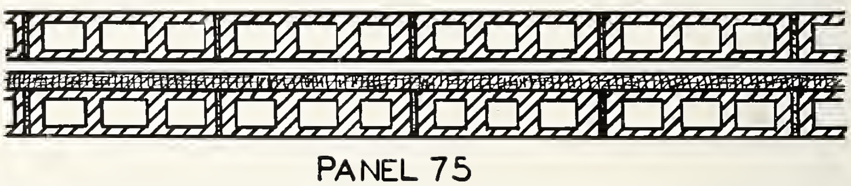


Panel 71.—*Hollow clay tile panel constructed of 4- by 12- by 12-inch partition tile, three cells; wood furring strips; paper; metal lath; scratch and brown coat of gypsum plaster; smooth, white finish.*

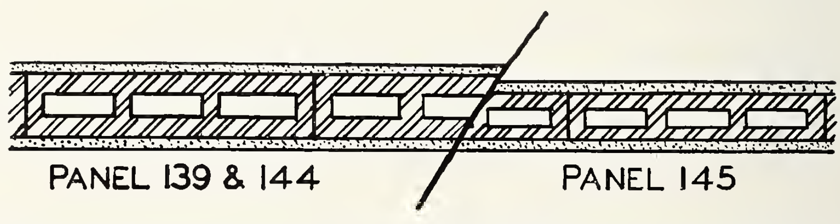
Panel 72.—*Hollow clay tile panel constructed of 4- by 12- by 12-inch partition tile; three cells; pads; wood furring strips; paper; metal lath; scratch and brown coats of gypsum plaster; smooth, white finish.*

Panel 73.—*Hollow clay tile panel constructed of 4- by 12- by 12-inch partition tile; three cells; wood furring strips; Masonite; brown coat gypsum plaster; smooth, white finish.*

Panel 74.—*Hollow clay tile panel constructed of 4- by 12- by 12-inch partition tile; three cells; wood furring strips; Insulite; brown coat of gypsum plaster; smooth, white finish.*



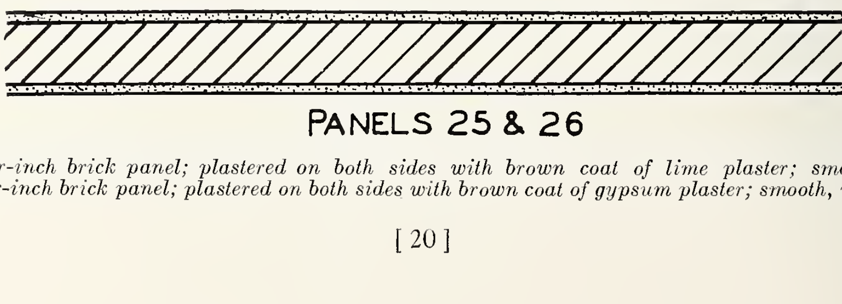
Panel 75.—*Double partition 3- by 12- by 12-inch hollow clay tile spaced $1\frac{3}{4}$ inches between sides; Flaxlinum, 1 inch thick and butted tight, was placed in the space between the tile; one side of the partition was carried on $\frac{1}{2}$-inch Flaxlinum strips, which were 4 inches wide, the strips being placed at the sides and top as well as the bottom.*



Panel 139.—*Cinder-block panel constructed of 4- by 8- by 18-inch standard Straub hollow cinder blocks; plastered on both sides with $\frac{5}{8}$ inch of brown-coat gypsum plaster; smooth, white finish.*

Panel 144.—*Cinder-block wall panel constructed of 4- by 8- by 16-inch cinder blocks; plastered on both sides with $\frac{5}{8}$ inch of brown-coat gypsum plaster; smooth, white finish.*

Panel 145.—*Cinder-block wall panel constructed of 3- by 8- by 16-inch cinder blocks; plastered on both sides with $\frac{5}{8}$ inch of brown-coat gypsum plaster; smooth, white finish.*

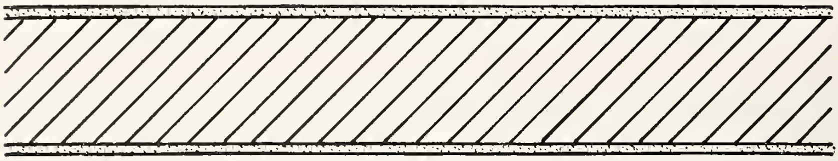


Panel 25.—*Four-inch brick panel; plastered on both sides with brown coat of lime plaster; smooth, white finish.*

Panel 26.—*Four-inch brick panel; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*

Table 1.—*Sound-transmission loss—wall structures*—Continued

Panel	Transmission loss (in decibels) at frequencies (cycles per second)													Weight
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	
CLAY TILE—Continued														
														*lb/ft*²
71	------	------	------	55. 6	------	52. 8	------	57. 3	57. 6	64. 0	------	55. 2	------	34. 0
72	------	------	------	55. 7	------	52. 4	------	53. 3	60. 2	69. 7	------	53. 8	------	34. 0
73	------	------	------	55. 3	------	53. 2	------	56. 8	68. 8	69. 6	------	55. 1	------	28. 0
74	------	------	------	52. 2	------	51. 9	------	60. 9	61. 1	61. 6	------	55. 0	------	34. 0
75	------	------	------	55. 2	------	50. 8	------	50. 8	65. 8	73. 2	------	52. 3	------	50. 0
CINDER BLOCK														
139	29. 8	------	------	30. 2	------	37. 7	------	47. 9	52. 7	------	59. 1	38. 6	------	29. 7
144	35. 5	------	36. 6	36. 9	41. 2	44. 4	46. 7	50. 9	55. 4	------	62. 4	44. 0	45. 6	35. 8
145	33. 8	------	36. 4	36. 5	40. 5	41. 9	44. 7	51. 2	56. 9	------	64. 3	43. 0	45. 1	32. 2
BRICK														
25	------	------	------	43. 1	------	------	------	46. 7	54. 5	56. 4	------	44. 9	------	------
26	------	------	------	46. 4	------	------	------	48. 8	58. 4	61. 3	------	47. 6	------	------

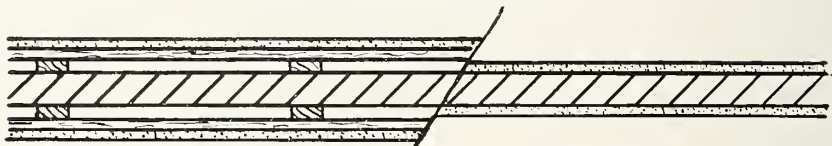


PANELS 79, 80, 81

PANEL 79.—*Eight-inch brick panel, New Hampshire brick, poor workmanship; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*

PANEL 80.—*Eight-inch brick panel, New Hampshire brick, good workmanship; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*

PANEL 81.—*Eight-inch brick panel, Mississippi brick, good workmanship; plastered on both sides with brown coat of gypsum plaster; smooth, white finish.*



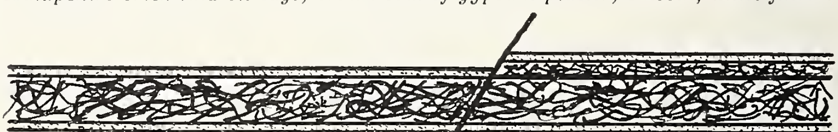
PANELS 82, 83, 84 PANEL 85

PANEL 82.—*New Hampshire brick laid on edge; furring strips wired; gypsum plaster board; plastered both sides with scratch and brown coats of gypsum plaster; smooth, white finish.*

PANEL 83.—*New Hampshire brick laid on edge; furring strips nailed; gypsum plaster board; scratch and brown coats of gypsum plaster; smooth, white finish.*

PANEL 84.—*New Hampshire brick laid on edge; furring strips nailed; $\frac{1}{2}$-inch Insulite; scratch and brown coats of gypsum plaster; smooth, white finish.*

PANEL 85.—*New Hampshire brick laid on edge; brown coat of gypsum plaster; smooth, white finish.*



PANEL 146 PANELS 147A, 147B

PANEL 146.—*Wall panel constructed of Thermax sheets 3 inches thick laid in mortar composed of gypsum plaster; plastered both sides with a brown coat of gypsum plaster; smooth, white finish.*

PANEL 147A.—*Wall panel constructed of Thermax sheets 3 inches thick laid in mortar composed of gypsum plaster; when the gypsum had set, 1-inch Thermax sheets were nailed on one face; plastered both sides with a brown coat of gypsum plaster; smooth, white finish.*

PANEL 147B.—*Wall panel; this panel was constructed the same as 147A, except that sisal-kraft paper was placed between the 1-inch and 3-inch Thermax, thus preventing any mortar penetrating through the joints of the 1-inch Thermax, and bonding it to the 3-inch Thermax.*

PANEL 154

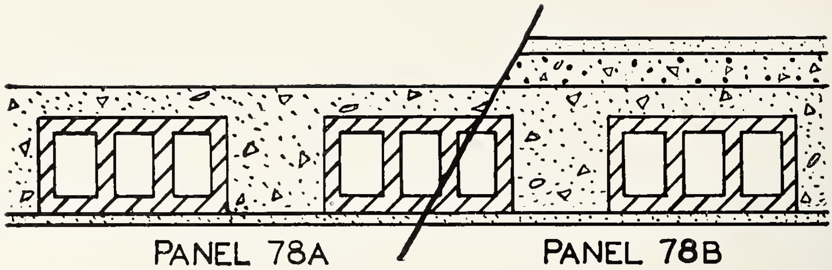
PANEL 154.—*Two-inch solid plaster partition; $\frac{3}{4}$-inch channel studs; Ecod metal lath with paper backing applied to one side; gypsum plaster; sand finish.*

PANEL 155.—*Partition of $3\frac{3}{4}$- by $4\frac{7}{8}$- by 8-inch glass bricks manufactured by Owens Illinois Glass Co.*

PANEL 93.—*Single sheet of aluminum 0.025 inch thick.*
PANEL 94.—*Single sheet of galvanized iron 0.03 inch thick.*
PANEL 95.—*Single sheet three-ply plywood $\frac{1}{8}$ inch thick.*
PANEL 96.—*Single sheet three-ply plywood $\frac{1}{4}$ inch thick.*
PANEL 98.—*Single sheet Insulite $\frac{1}{2}$ inch thick.*
PANEL 101.—*Single sheet of heavy wrapping paper.*
PANEL 102.—*Single sheet of double-strength glass $\frac{1}{8}$ inch thick.*
PANEL 103.—*Single sheet of plate glass $\frac{1}{4}$ inch thick.*
PANEL 106.—*Single sheet of standard Celotex $\frac{7}{16}$ inch thick.*
PANEL 110.—*Single sheet of lead $\frac{1}{8}$ inch thick.*
PANEL 111.—*Single sheet of lead $\frac{1}{16}$ inch thick.*

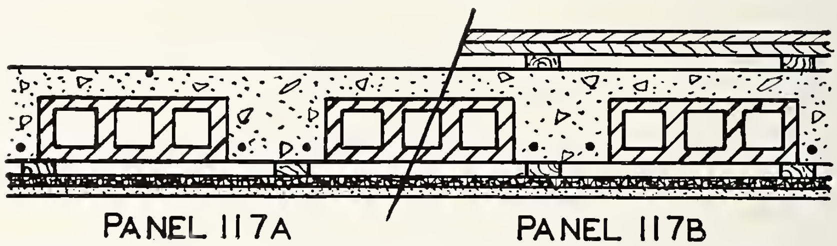
TABLE 1.—*Sound-transmission loss—wall structures*—Continued

Panel	Transmission loss (in decibels) at frequencies (cycles per second)													Weight
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	
							BRICK—Continued							
														lb/ft²
79				47. 7		48. 1		55. 6	56. 3	60. 4		50. 5		92. 0
80				47. 7		49. 4		57. 0	59. 2	70. 0		51. 4		97. 0
81				50. 2		47. 6		55. 5	63. 5	69. 2		51. 1		87. 0
82				52. 1		47. 4		56. 5	53. 9	57. 8		52. 0		36. 5
83				46. 8		44. 3		54. 4	61. 3	69. 2		48. 5		38. 2
84				48. 8		50. 5		59. 8	55. 8	58. 2		53. 0		33. 3
85				40. 0		36. 9		48. 7	59. 1	59. 1		41. 9		31. 6
							THERMAX							
146	25. 8		32. 0	32. 0	32. 2	33. 3	35. 3	32. 4	37. 5		52. 9	33. 0	34. 8	
147A	33. 4		33. 1	35. 9	36. 0	37. 6	43. 7	45. 2	47. 1		62. 9	39. 7	41. 7	23. 5
147B	32. 1		40. 1	40. 5	43. 9	46. 3	50. 2	51. 2	52. 1		70. 5	46. 4	47. 4	
							SOLID PLASTER PARTITION							
154	38. 0		37. 2	33. 6	33. 4	36. 2	35. 8	41. 0	48. 1		55. 5	36. 0	39. 9	
							GLASS BRICK							
155	30. 2		36. 2	34. 7	39. 4	40. 5	45. 1	48. 6	49. 0		43. 4	41. 7	40. 8	
							SINGLE LAYERS OF MATERIAL							
93				17. 9		13. 2		17. 7	23. 2	25. 3		16. 3		0. 35
94				25. 3		20. 5		28. 8	35. 0	31. 7		24. 9		1. 2
95				19. 0		17. 5		22. 0	26. 7	25. 5		19. 5		0. 52
96				21. 0		20. 7		25. 5	26. 0	21. 9		22. 4		. 73
98				22. 2		20. 2		24. 1	20. 9	27. 1		22. 2		. 75
101				1. 4		1. 5		1. 7	3. 3	3. 7		1. 5		. 016
102				26. 2		27. 4		30. 8	33. 0	29. 2		28. 1		1. 6
103				32. 6		30. 9		33. 5	34. 2	32. 2		32. 3		3. 5
106				22. 4		17. 3		23. 4	27. 4	24. 6		21. 0		0. 66
110				31. 0		27. 2		37. 5	43. 8	32. 6		31. 9		8. 2
111				31. 8		33. 2		32. 0	32. 1	32. 5		32. 3		3. 9



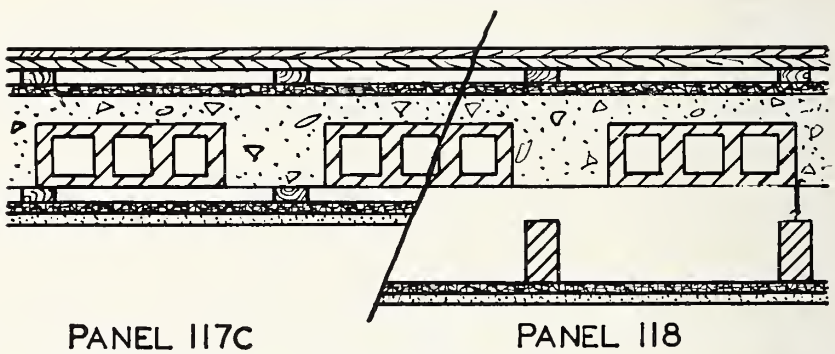
Panel 78A.—*Combination floor panel constructed of 6- by 12- by 12-inch three-cell partition tile; the ceiling of this panel was finished with a brown coat of gypsum plaster; smooth, white finish.*

Panel 78B.—*Same as panel 78A, except 2 inches of cinder concrete and 1 inch of cement were added to upper surface.*



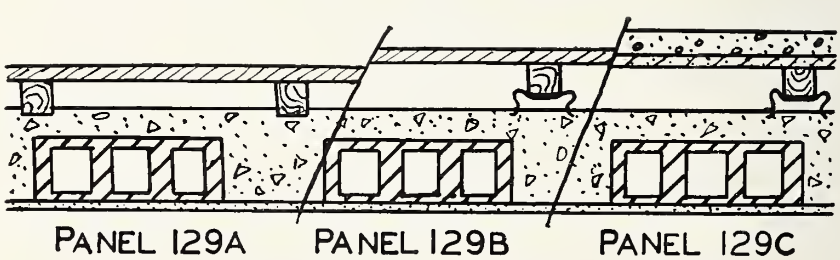
Panel 117A.—*Combination floor panel constructed of 4- by 12- by 12-inch three-cell partition tile; ceiling was finished with furring strips, ½-inch Insulite, and plaster.*

Panel 117B.—*Same as panel 117A, except floating floor was added, which consisted of 1- by 2-inch nailing strips, rough flooring, and ⅜-inch oak flooring.*



Panel 117C.—*Same as panel 117B, except ½-inch Insulite was added between masonry slab and floating floor.*

Panel 118.—*Same as panel 117C, except ceiling was stripped off and suspended ceiling attached by means of wires.*



Panel 129A.—*Combination floor panel constructed of 4- by 12- by 12-inch, 3-cell partition tile; the ceiling of this panel was finished with ½ inch of brown coat gypsum plaster and a smooth, white finish coat; the floor surface consisted of 13/16-inch oak flooring, nailed to 2- by 2-inch nailing strips 16 inches on centers, which were grouted into the concrete.*

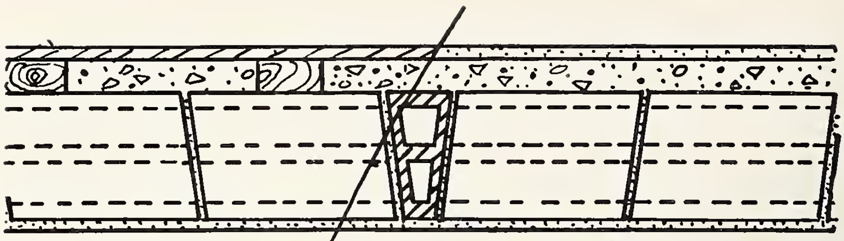
Panel 129B.—*Same as panel 129A, except that United States Gypsum resilient steel clips were inserted between the concrete and nailing strips.*

Panel 129C.—*Same as panel 129B, except that the oak flooring was removed, and ½-inch gypsum plasterboard was attached to the nailing strips and 1½-inch Hydrocal was applied on top of the plasterboard.*

Table 2.—*Sound-transmission loss—floor structures*

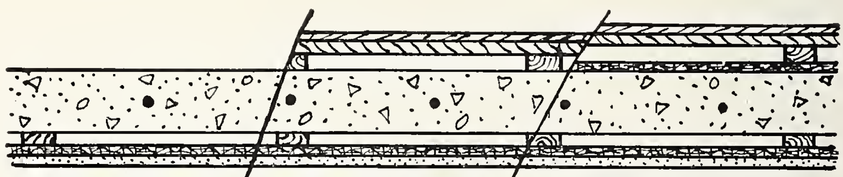
Panel number	Transmission loss (in decibels) at frequencies (cycles per second)														
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	Tapping	Weight
COMBINATION															
															lb./ft²
78A				51. 2		46. 8		49. 6	60. 4	54. 0		49. 2			83
78B				52. 4		48. 0		49. 9	54. 6	48. 1		50. 1			109
117A		56. 5		56. 6		55. 8		57. 7	58. 8	57. 2		56. 7		5. 1	69. 8
117B		62. 7		63. 1		61. 0		65. 9	73. 7	67. 4		63. 3		34. 0	73. 5
117C		63. 6		70. 3		63. 4		63. 5	68. 7	68. 0		65. 7		35. 0	74. 2
118		68. 0		67. 9		65. 8		72. 1	<76. 0	<77. 0		68. 6		51. 0	72. 8
129A	35. 9			37. 7		38. 6		46. 8	53. 8		55. 1	41. 0		22. 6	
129B	37. 0			46. 6		58. 3		68. 5	73. 2		([a])	57. 8		33. 0	
129C	42. 6			49. 5		60. 9		71. 3	76. 7		([a])	60. 6		38. 5	

[a] Sound inaudible.



PANEL 76.—*Flat arch floor panel constructed of 8-inch, 4-cell tile; plastered with brown coat gypsum plaster and smooth, white finish; two by fours were fastened to the top surface approximately 16 inches on center and the space between filled with cinder concrete; floor was finished with hardwood flooring.*

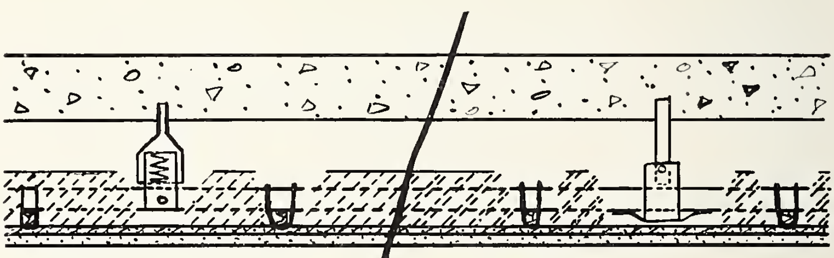
PANEL 77.—*Same as panel 76, except the floor was finished with 2 inches of cinder concrete and 1 inch of cement.*



PANEL 116A.—*Reinforced concrete flat slab type of floor construction; Insulite furred out and applied as ceiling; brown coat gypsum plaster; smooth, white finish.*

PANEL 116B.—*Same as panel 116A, except floating floor was added, which consisted of 1- by 2-inch nailing strips, rough flooring, and 3/8-inch oak flooring.*

PANEL 116C.—*Same as panel 116B, except 1/2-inch Insulite was added between concrete slab and floating floor.*



PANEL 156.—*Floor panel composed of a 4-inch concrete slab; suspended ceiling of gypsum lath; 1/4-inch brown coat gypsum plaster; finished with 1/2-inch acoustic plaster; 3-inch ground cork on top of gypsum lath; hangers were special coiled springs.*

PANEL 158.—*Same as panel 156, except 4 inches of rock wool was used in place of the ground cork.*

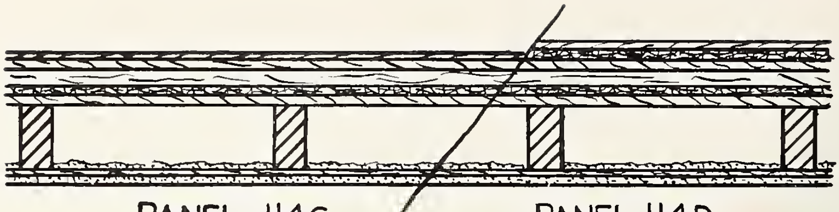
PANEL 157.—*Same as panel 156, except a flat spring was used in place of the coiled spring in the hanger and Thermofil was used in place of cork.*

PANEL 114A.—*Floor panel; wood joists; plaster on wood lath applied to lower side, subflooring and 3/8-inch finish flooring to upper side.*

PANEL 114B.—*Same as panel 114A, with exception of flooring; 1/2-inch Insulite between rough and finished floors.*

Table 2.—*Sound-transmission loss—floor structures*—Continued

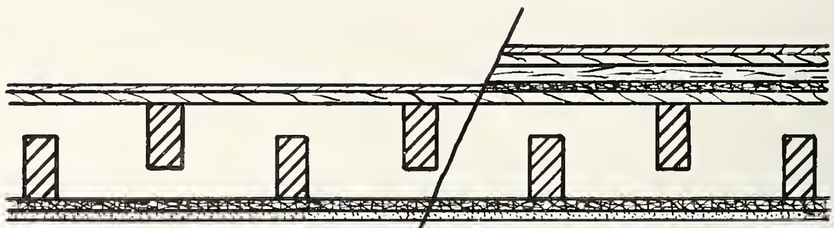
Panel number	Transmission loss (in decibels) at frequencies (cycles per second)														
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average: 256 to 1,024	Average: 128 to 4,096	Tapping	Weight
FLAT ARCH															
															lb/ft²
76	----	----	----	46. 3	----	46. 8	----	47. 8	54. 5	54. 4	----	47. 0	----	----	76
77	----	----	----	46. 7	----	47. 1	----	47. 4	50. 5	49. 1	----	47. 1	----	----	85
CONCRETE SLAB															
116A	----	50. 9	----	54. 8	----	58. 7	----	56. 5	53. 2	56. 0	----	56. 7	----	1. 2	54. 4
116B	----	58. 9	----	57. 0	----	55. 4	----	67. 6	65. 2	62. 5	----	60. 0	----	30. 0	58. 1
116C	----	57. 9	----	58. 2	----	55. 8	----	66. 3	67. 3	62. 3	----	60. 1	----	33. 0	58. 9
156	39. 3	----	46. 5	43. 8	47. 9	50. 8	56. 1	60. 0	67. 5	----	76. 7	51. 7	54. 3	11. 3	----
158	36. 7	----	45. 5	47. 1	49. 6	51. 4	57. 0	60. 0	69. 0	----	76. 9	53. 0	54. 8	11. 5	----
157	40. 8	----	43. 6	46. 6	50. 1	51. 0	55. 7	59. 6	67. 8	----	76. 5	52. 6	54. 6	12. 3	----
WOOD JOIST															
114A	----	47. 9	----	46. 8	----	40. 7	----	50. 1	48. 8	47. 4	----	45. 9	----	14. 0	----
114B	----	47. 7	----	48. 3	----	40. 6	----	50. 3	48. 9	46. 6	----	46. 4	----	14. 0	----



PANEL 114C PANEL 114D

Panel 114C.—*Same as panel 114A, with exception of flooring; rough flooring; $\frac{1}{2}$-inch Insulite; floating floor, consisting of nailing strips, rough and finish flooring.*

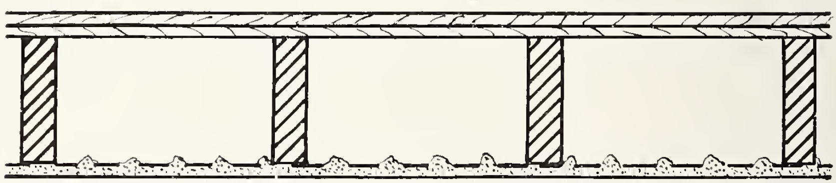
Panel 114D.—*Same as panel 114C, except Insulite was inserted between rough and finished floor in floating floor.*



PANEL 115A PANEL 115B

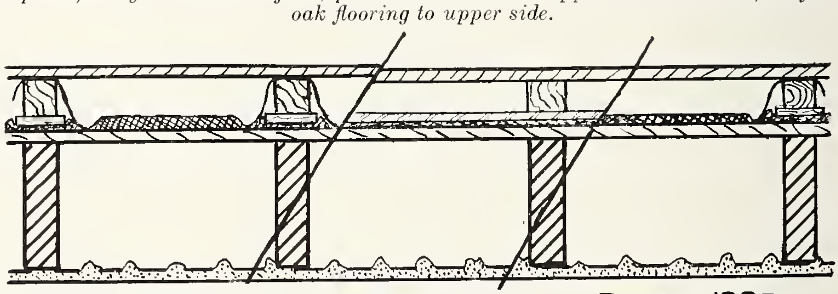
Panel 115A.—*Suspended ceiling; wood joists; $\frac{1}{2}$-inch Insulite plaster applied as ceiling; rough floor; finish floor applied as flooring; ends of ceiling and floor joists were nailed to a common support.*

Panel 115B.—*Same as panel 115A with exception of flooring; rough flooring; $\frac{1}{2}$-inch Insulite; floating floor consisting of 1- by 2-inch nailing strips, rough flooring, and $\frac{3}{8}$-inch oak flooring.*



PANEL 130

Panel 130.—*Floor panel, 2- by 8-inch wood joist; plaster on metal lath applied to lower side, subflooring and $^{13}/_{16}$-inch oak flooring to upper side.*



PANELS 132A, 132C PANEL 133A PANEL 133B

Panel 132A.—*Floor panel, 2- by 8-inch wood joist; plaster on metal lath applied to lower side, subflooring to upper side; 1-inch Balsam Wool was laid over the subfloor and on this were placed small squares ($2\frac{1}{2}$ by $2\frac{1}{2}$ inches) of hard-pressed Nuwood spaced 16 inches on centers in each direction; nailing strips $1\frac{3}{4}$ by $1\frac{3}{4}$ inches were placed on top of these Nuwood squares and held in place by a metol strap; the finish floor ($^{13}/_{16}$-inch oak) was nailed on top of these nailing strips.*

Panel 132B.—*This was a floor in an apartment house and supposed to be constructed the same as panel 132A.*

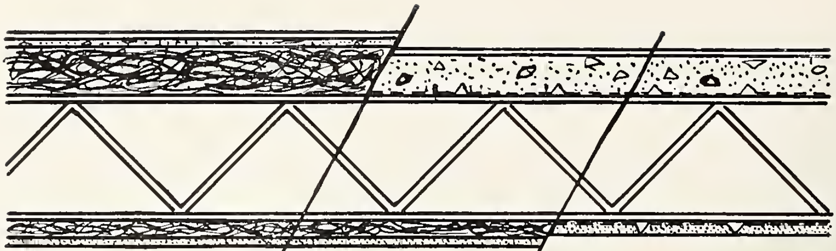
Panel 132C.—*This panel was the same as panel 132A, except that $\frac{1}{2}$-inch Balsam Wool was used nistead of 1-inch.*

Panel 133A.—*Floor panel, 2- by 8-inch wood joist; plaster on metal lath applied to lower side, subflooring to upper side; $\frac{1}{2}$-inch balsam wool was laid over subfloor and $\frac{1}{2}$-inch Nuwood was placed on top of the balsam wool; $1\frac{3}{4}$- by $1\frac{3}{4}$-inch nailing strips were spaced 16 inches on centers on top of the Nuwood and held in position by driving one nail at each end through the strip and into the subfloor; a finish floor of $^{13}/_{16}$-inch oak was opplied on top of the nailing strips.*

Panel 133B.—*Floor panel; this panel was the same as panel 133A, except that the sheets of Nuwood were removed and strips of Nuwood $2\frac{1}{2}$ inches wide were placed under the nailing strips.*

TABLE 2.—*Sound-transmission loss—floor structures*—Continued

Panel number	Transmission loss (in decibels) at frequencies (cycles per second)														
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	Tapping	Weight
WOOD JOIST—Continued															
															lb/ft^2
114C	----	57. 6	----	57. 5	----	54. 8	----	62. 4	57. 6	56. 6	----	58. 2	----	22. 0	----
114D	----	57. 9	----	60. 1	----	53. 5	----	62. 7	55. 7	56. 7	----	58. 8	----	22. 0	----
115A	----	52. 6	----	53. 6	----	49. 2	----	54. 9	55. 3	55. 0	----	52. 6	----	22. 0	12. 6
115B	----	62. 4	----	65. 3	----	57. 3	----	68. 8	62. 3	65. 0	----	63. 8	----	30. 0	16. 1
130	23. 2	----	----	23. 5	----	33. 9	----	40. 6	47. 6	----	59. 7	32. 7	----	11. 1	17. 1
132A	31. 8	----	----	35. 4	----	48. 7	----	56. 6	67. 5	----	80. 0	46. 9	----	19. 4	----
132B	26. 4	----	----	31. 1	----	50. 4	----	61. 7	64. 0	----	80. 0	47. 7	----	----	----
132C	25. 5	----	----	35. 9	----	48. 1	----	56. 1	70. 1	----	80. 0	46. 7	----	17. 1	----
133A	23. 6	----	----	33. 5	----	47. 5	----	55. 8	67. 1	----	81. 8	45. 6	----	15. 3	15. 0
133B	23. 1	----	----	34. 8	----	51. 2	----	60. 3	72. 8	----	80. 0	48. 8	----	20. 2	----

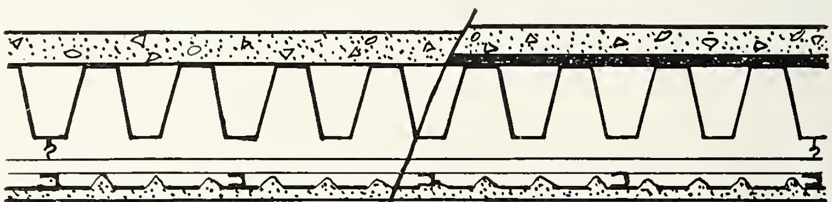


PANEL 137 PANEL 137A PANEL 137B

PANEL 137.—*Floor panel constructed of 8-inch Mac Mar joist, with 3-inch Thermax clipped on top and 1-inch Thermax clipped on bottom of joist; ½ inch of concrete was poured on top of the 3-inch Thermax; floor was finished by cementing ¼-inch battleship linoleum on top of the concrete; ceiling was finished by applying a brown coat of gypsum plaster and a smooth, white finish coat.*

PANEL 137A.—*Same as panel 137, except 3-inch Thermax was removed and standard high rib metal lath attached to top of joist; 2½ inches of concrete was poured on top of lath; battleship linoleum was cemented to top of concrete.*

PANEL 137B.—*Same as panel 137A except ceiling of panel 137A was removed and standard high rib metal lath was attached to under side of joist; scratch and brown coat gypsum plaster; smooth, white finish.*



PANEL 136A PANEL 136B

PANEL 136A.—*Floor panel constructed by using steel floor section with flat top; top of this section was covered with 2 inches of concrete and a suspended metal lath and plaster ceiling attached to the bottom, leaving approximately 4 inches between the metal section and plaster.*

PANEL 136B.—*Floor panel; same as panel 136A, except that the 2-inch concrete slab was removed and ½-inch of emulsified asphalt applied directly to the top of the steel section; a 2-inch concrete slab was cast on top of this asphalt.*

Table 2.—*Sound-transmission loss—floor structures*—Continued

Panel number	Transmission loss (in decibels) at frequencies (cycles per second)													
	128	165	192	256	384	512	768	1,024	2,048	3,100	4,096	Average 256 to 1,024	Average 128 to 4,096	Tapping	Weight
STEEL JOIST															
															lb/ft²
137	30. 6	-----	51. 0	43. 7	46. 1	51. 9	55. 2	58. 2	64. 5	-----	74. 2	51. 0	52. 8	11. 7	------
137A	36. 8	-----	45. 7	46. 6	47. 6	52. 0	55. 8	59. 3	65. 2	------	74. 7	52. 3	53. 7	13. 6	------
137B	40. 3	-----	41. 1	48. 4	50. 7	53. 6	58. 8	66. 0	63. 4	------	71. 8	55. 5	54. 9	13. 1	------
STEEL SECTION															
136A	34. 0	-----	43. 9	43. 2	50. 8	51. 7	57. 0	59. 2	64. 6	------	71. 9	52. 4	52. 9	6. 5	------
136B	41. 9	-----	48. 9	52. 4	56. 3	60. 0	64. 2	66. 7	77. 3	------	83. 0	59. 9	61. 2	21. 1	------

XII. SELECTED REFERENCES

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Washington, November 8, 1938.

The *National Bureau of Standards* was established by act of Congress, approved March 3, 1901, continuing the duties of the old Office of Standard Weights and Measures of the United States Coast and Geodetic Survey. In addition, new scientific functions were assigned to the new Bureau. Originally under the Treasury Department, the Bureau was transferred in 1903 to the Department of Commerce and Labor (now the United States Department of Commerce). It is charged with the development, construction, custody, and maintenance of reference and working standards, and their intercomparison, improvement, and application in science, engineering, industry, and commerce.

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- Inductance and Capacitance
- Electrical Instruments
- Magnetic Measurements
- Photometry
- Radio
- Underground Corrosion
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- Telephone Standards

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- Mass
- Time
- Capacity and Density
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- Thermal Expansivity, Dental Research, and Identification
- Weights and Measures Laws and Administration
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- Limit Gages

Heat and Power
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- Physical Chemistry
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- Testing and Specifications
- Fiber Structure
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- Glass
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- Enameled Metals
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- Masonry Construction
- Lime and Gypsum
- Stone

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- Consumer Contacts and Labeling

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- Information
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- Glassblowing
- Shop Tools and Equipment
- Materials and Supplies

Operation of Plant
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- Electrical
- Piping
- Grounds
- Construction
- Guard
- Janitorial